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SHOCK STUDIES OF CERAMICS

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by

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13. ABSTRACT ***(Maximum 200 Words)***

The report covers the 3 month visit of Dr D Dandekar of ARL, USA to the Cavendish Laboratory. The project involved an exchange of ideas in the area of shock physics and the design, sample preparation and testing of various materials in the plate-impact facility. The report describes the plate impact facility and the techniques used. Data is reported on a series of spall experiments on PMMA (polymethyl methacrylate). Samples of SiC and ceramics prepared by hot-isolation pressing (HIPing) and pressure assisted densification (PAD) were polished to the tolerances required. This research is still ongoing. The study visit was valuable in developing collaboration between ARL and the Cavendish.

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SHOCK STUDIES OF CERAMICS

1. Background

This covered a 3 month period visit, starting September 2001, by Dr D P Dandekar of the Army Research Laboratory, USA.

The area of research involved shock studies of materials using the technique of plate-impact. This is a technique of interest to both ARL and Cambridge. The aims were (i) to study specific materials, (ii) to build up useful collaboration between the two groups.

2. The plate-impact method and the facilities at the Cavendish Laboratory

Impulsive loading conditions need to be considered in many industries including structural strength of vehicles during crash situations, lightweight body armour for personnel and military vehicles, aero-engines and space-craft. As such situations arise under diverse conditions, there is a need to be take account of these in the materials selection and design process. To do this effectively, it is necessary to understand the material response to high stress loading at high loading rates.

In plate impact experiments, the impacting plate is fired at a target. If there is good alignment, a 1-d pulse of chosen pressure and duration can be produced. The pressure generated depends on the Hugoniot properties of the plate and target materials and the impact velocity. The duration is controlled by the to and fro transit time of the shock in the plate. The 1-d pulse is maintained until release waves from the plate and target boundaries reach the target axis. This effectively defines the "window" for accessing data.

All the experiments reported here were carried out using the single stage gas gun in the Cavendish Laboratory (figure 1).

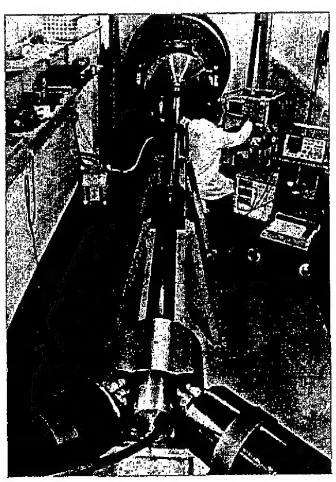

Figure 1: Plate impact facility at Cavendish Laboratory

The projectile consists of a flyer plate attached to a polycarbonate sabot. It is placed in the barrel and held against the breech block by a vacuum. Two "O"rings on the sabot, block the exits of the two reservoirs. This arrangement is known as a "wrap-around" breech. The reservoirs are filled with propellant gas using pressurised cylinders and compressors operating up to 350 bar. When using helium as a propelling gas, velocities of up to 1.2 km/s can be achieved. As noted above, by altering the impact speed and the material of the flyer plate, the impact stress can be varied.

The gun is fired by the rotation of a solenoid which breaks the vacuum behind the projectile causing it to move forward, clearing the reservoir exits. The high pressure gas then accelerates the sabot and flyer plate down the barrel. The barrel is 5 m long, has a 50 mm bore accurate to ± 25 μm along its length.

Projectile velocity is measured to an accuracy of ±0.5% by means of four pairs of pins which are positioned at accurately known distances before the target. As the conductive flyer passes a pair of these pins, it completes a circuit giving a shorting signal which is recorded on an oscilloscope. Graphite pins, diameter 0.3 mm, are used to measure velocities below 600 m/s and brass pins for higher velocities.

Stress levels are measured in the sample with Manganin gauges or using velocity interferometry (VISAR; velocity interferometry system for any reflector).

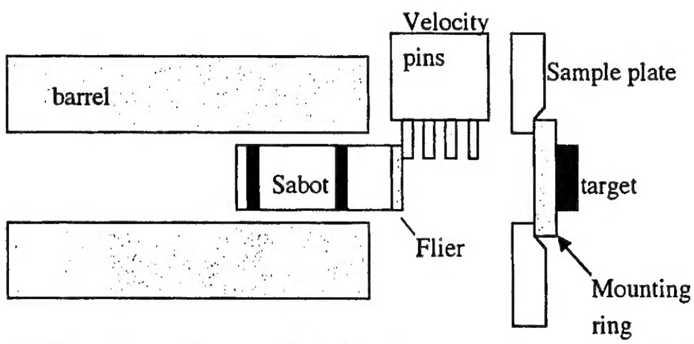

Figure 2: Experimental set-up for plate impact experiment (not to scale).

For a 1-d loading impact, the sample, mounting, mounting ring, sample plate and flyer plate need to be flat *and* aligned. At the end of production, the projectile is held in a lathe and the flier plate is faced to be perpendicular to the rotation axis of the sabot. The sample plate is aligned to an accuracy of 0.1 μm by use of a dial gauge and a plug inserted in the end of the barrel for each experiment.

The mounting ring is machined flat and parallel to better than 10 μm over its 14 cm diameter. The central hole of the ring is diameter 6 cm which allows the projectile to pass through after the impact. The ring is lightly pressed into place on the sample plate, figure 2. The target is fixed to the ring using metal filled epoxy, which has good adhesion and minimal expansion on setting; care is taken not to get adhesive between the target and

mounting ring. At impact, the sabot is partially in the barrel so ensuring that there is no yaw due to gravity acting on the projectile.

The particle velocity-time history of a specularly reflecting surface during an impact can be determined using VISAR. It is important that the surface is not polished to an optical finish because such a finish is unlikely to be preserved at high stress. This technique was developed by Barker et al. in the late 60's and early 70's.

The reflected laser light is captured and split into two beams, one of which is passed through a glass cylinder known as an "etalon". Because the refractive index of glass is higher than that of air, the light in this beam is slowed down and delayed with respect to the other beam which passes through air. If the target is stationary, the interference pattern will not change with time when the two beams are recombined. For an accelerating target, however, the reflected beam will be doppler shifted, and due to this change in frequency, there is a beat frequency when the two beams are recombined. Changes in velocity can be measured by recording this interference. The time delay is dependent on the "etalon" length, so it is possible to adjust the system to ensure that an appropriate amount of acceleration per beat (fringe) is obtained. VISAR effectively measures the rear surface particle velocity from which a shock pressure versus time trace can be obtained. Rise times of ~ 2ns can be followed.

Various gauge types are also used. These involve cutting up the target, mounting the gauge and re-assembly of the target. Gauges can be used to measure longitudinal or lateral stresses. The longitudinal gauge gives "in target" pressure information, the subtraction of the lateral stress from the longitudinal stress gives twice the shear strength.

3. <u>Results</u>

(a) Spall in Polymer Systems

The spall strength of a material is the measure of its high-rate tensile strength. Spall occurs when the release fans from the impactor and the target free surfaces overlap (figure 3). The prediction and the modelling of spall requires an accurate knowledge of both the shock properties, such as the Hugoniot, and the release process, the isentrope, of the system.

Spall strengths have been measured in many materials. The variation in value as a function of the initial shock input and the incipient formation of the spall plane have been studied. Modelling of such systems is non-trivial and requires the successful integration of several steps; the passage of shock waves through an uncompressed material, the dispersion of the release waves, the interaction of the releases and the fracture limit.

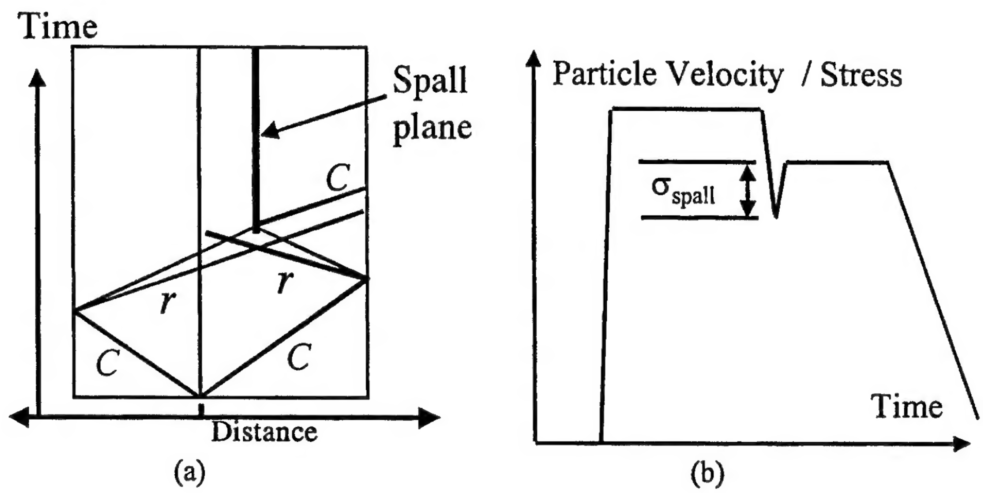

FIGURE 3. (a)Wave propagation diagram, c = compression wave, r = release fan, (b) Velocity of rear of target plate.

In metals, a great deal of recent interest has been directed into the studies of the mesoscale properties where individual grains affect the signal. In polymers, the situation is more complex, the fracture does not form in an intra or trans-granular fashion, rather it passes through amorphous or semi-crystalline regions. Some polymers such as polycarbonate show very large strain to failure values. In this study, three groups of experiments were performed each with a different impactor: target thickness. The spall signature can be seen to vary with the impact velocity and the geometry in a non-trivial fashion.

Table 1.Spall Experiemnts on Perspex (PMMA)

Target / mm	Impactor / mm	Velocity km / s	Shot Code
12	6	0.301	020702a
12	6	0.599	020702b
8	4	0.753	020702c
24	4	0.300	011009a
12	4	0.300	011009b
12	4	0.600	011012a
6	2	0.300	011012b
6	2	0.599	011020a
12	4	0.750	011020b

Targets and Impactors were PMMA plates in all cases

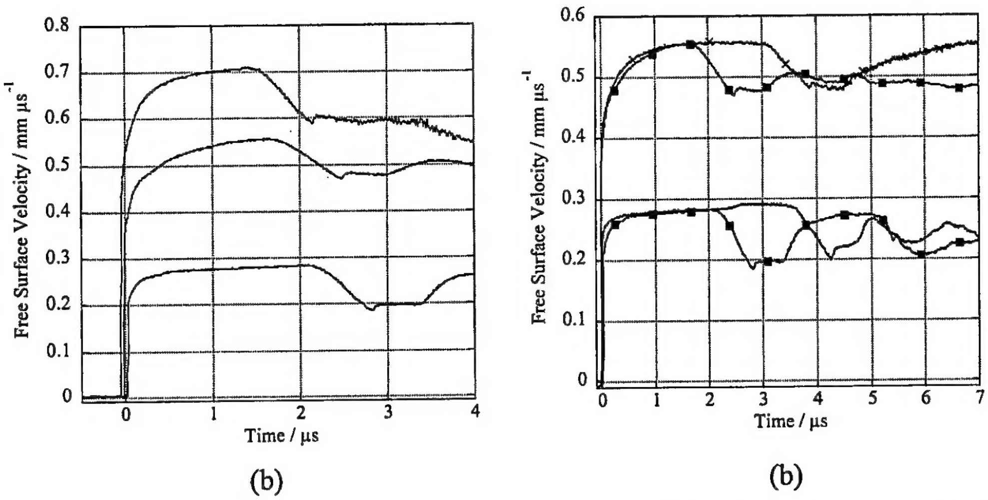

Figure 4 Spall traces of (a) 4 mm impactor against 12 mm target at 300, 600 and 750 m $^{s-1}$ and (b) 4 mm impactor and 6 mm impactors against 12 mm targets at 300 and 600 m s^{-1}

The traces in figure 4 (a) show the decay in the spall strength with increased impact velocity while (b) shows the effect of geometry on the signal. It appears that at a given shock level the spall strength decreases with the amount of time it is under loading, a decrease can also be produced by impacting at higher velocities.

(b) Effect of ceramic production on material properties

Blocks of ceramic can be produced by sintering or compaction processes such a hot-isostatic pressing (HIPping) or pressure assisted densification (PAD). The blocks produced by these methods may exhibit different properties along each axis. It is, therefore, important to measure the shock parameters along the axises of a SiC block made using PAD technology. The starting block is typically $10 \times 10 \times 5$ cm^3.

The block is sectioned into thin plate 2 – 3 mm thick along the main axises and the ceramic subjected to plate impact. VISAR is being used to determine the elastic limit and spall strength to see if either of these major parameters is affected by the orientation. Due to the production time required for the thin plates, these experiments are on-going.

(c) Failure wave studies in SiC ceramics

Samples of SiC-1 and SiC-2 have been produced and will be subject to impact in order to determine the movement and the effect of failure fronts with the material. This project involves using two SiC vairants and analysing the decay of the spall signal and the detection of any reloading in the pulses. Both the decay in spall strength of the material due to comminution and the reloading signal, due to material densification, are a direct result of the movement of the failure front within the material. These experiments were subject to the same time constraints as those outlines in (b). This research is on-going.

4. Conclusions

The 3 month period was valuable to both Dr Dandekar and the Cavendish. Dr Dandekar gave talks and a colloquium and all members of the group discussed their projects with Dr Dandekar.

The research programme was, in retrospect, too ambitious for completion in 3 months. The ceramic samples needed precision polishing and this took time. Data from the ceramics will be obtained over the next 2 months as shots are scheduled on the plate impact facility.

There now continues to be regular and useful contact with Dr Dandekar and other researchers at ARL.